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# Assessment of Different Thermal Expansion Properties

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*Abstract*— **In this paper MEMS sensor array is studied by thermal expansion due to change in volume in response to change in temperature, through heat transfer. Thermal analysis of sensor array for material selection is done. For this thermal analysis Joule heating properties can be used to create thermal expansion which results in displacement. For large displacement at small voltages electrothermal mechanism is used. And also by applying electric potential effect of temperature on electrical and thermal conductivity is studied. COMSOL multiphysics and simulation software is used to study relation among the electric field, heat transfer and structure expansion. And also to evaluate COMSOL heat transfer module using MATLAB.**

*Keywords*— **Sensor Array, COMSOL Multiphysics, Different Material, MATLAB, Thermal Expansion.**

## I. INTRODUCTION

MEMS are micrometer-scale devices that combine electrical and mechanical elements. They have been used in diverse applications, from display technologies to sensor systems to optical networks. MEMS are attractive for many applications because of their small size and weight, which allow systems to be miniaturized [7] having feature size ranging from micrometers to millimeters. They may be fabricated using methods analogous to those used to construct integrated circuits and they have the potential of providing significant cost advantage when batch fabricated. Their sizes also make it possible to integrate them into a wide range of systems. Feature sizes may be made with size on the order of the wavelength of light, thus make them attractive for many optical applications [7]. MEMS consist of mechanical elements sensors, actuators and electrical and electronics devices on a common silicon substrate.

In the most general form, MEMS consist of mechanical microstructures, microsensors, microactuators and microelectronics, all integrated on same silicon chip. Microsensors detect changes in the system's environment by measuring mechanical, thermal, magnetic, chemical or electromagnetic information or phenomenon. Microelectronics process this information and signal the microactuators to react and create some form of changes to the environment. MEMS devices are very small, their components are usually microscopic. Levers, gears, pistons as well as motors and even steam engines have all been fabricated by MEMS. MEMS is a manufacturing technology, a paradigm for designing and creating complex mechanical devices and systems [8]. The most popular material used for MEMS is silicon for its semiconductor, physical and commercial properties.

*Thermal Expansion*

Thermal expansion can be used for generating force or displacement by changing temperature. In response to change in temperature, the matter changes its volume due to thermal expansion. The degree of expansion divided by the change in temperature is called the material's coefficient of thermal expansion which varies with change in temperature. Some material contract to a limited size with increase in temperature, occurs within limited temperature ranges poses negative coefficient of thermal expansion. The coefficient of thermal expansion is very small for most materials, hence amount of displacement would be small. Thermal expansion coefficient in liquid is higher than in solids and thermal expansion of gases follow ideal gas law [1].

### Mathematical Modelling

*Joule Heating*

For heat transfer in solids, Joule Heating Model in COMSOL uses the heat equation as the mathematical model

$$\rho\ C_p\ \Delta T/\Delta t - \Delta\ (k,\Delta t) = Q(1)$$

(1)

With change in temperature, dimensional change (volume and length) occurs in all the materials.

Volumetric Thermal Expansion Coefficient, commonly denoted as $\alpha$, is the ratio of relative change of volume to the degree of temperature variation [1]

$$\alpha = \Delta V/V/\ \Delta T \qquad (2)$$

Linear Thermal Expansion Coefficient is change in only one direction due to change in temperature variation [1].

$$\beta = \ \Delta L/L/\ \Delta T \qquad (3)$$

Volumetric and Linear Expansion Coefficient can be related to each other as [1]

$$\alpha = 3\beta$$

(4)

## Observations

An array of sensors can be designed using various shapes to study the effects of different properties when temperature changes. A study has been performed on it using simple design as in U-shape as shown in Fig. 1[3].

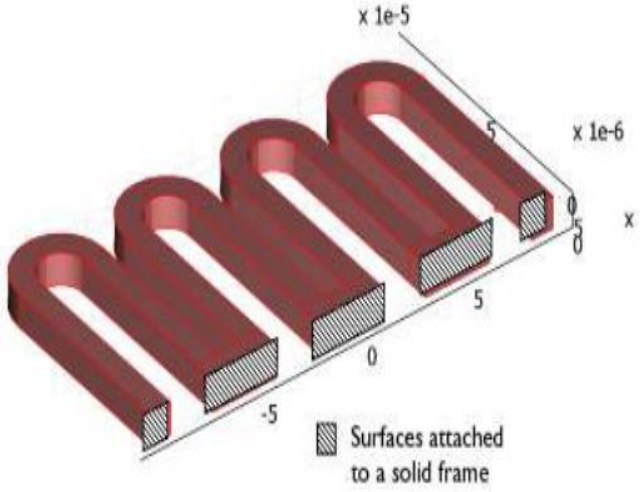

Fig. 1 Model Geometry of the Device

So, various properties can be studied on this, as temperature distribution in the device when heat source is present at any of its edge as in Fig. 2[3].

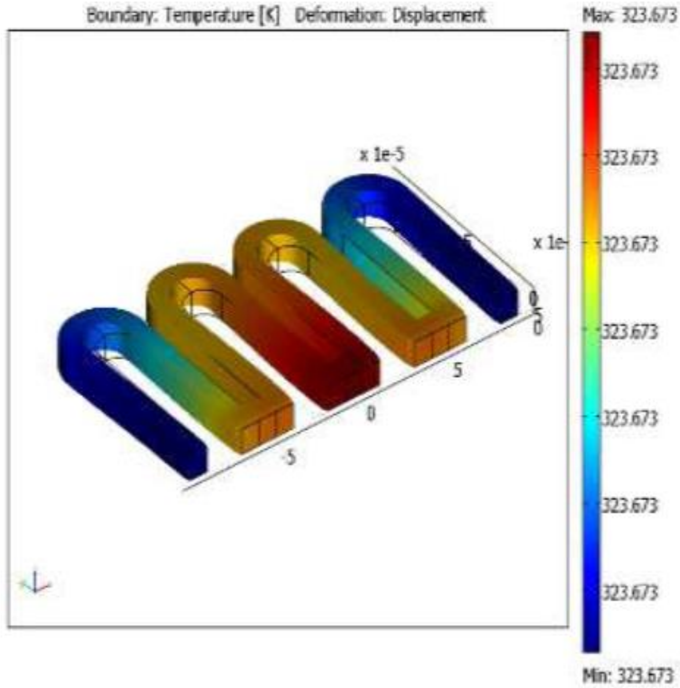

Fig. 2 Temperature Distribution of the Device at 298 K

Similarly, it can be studied on different shape for example on zigzag shape. Figure 3 shows the temperature distribution in the device. The heat source increases the temperature to 333 K from an ambient temperature of 298 K. The edges of the original geometry are shown in black [1].

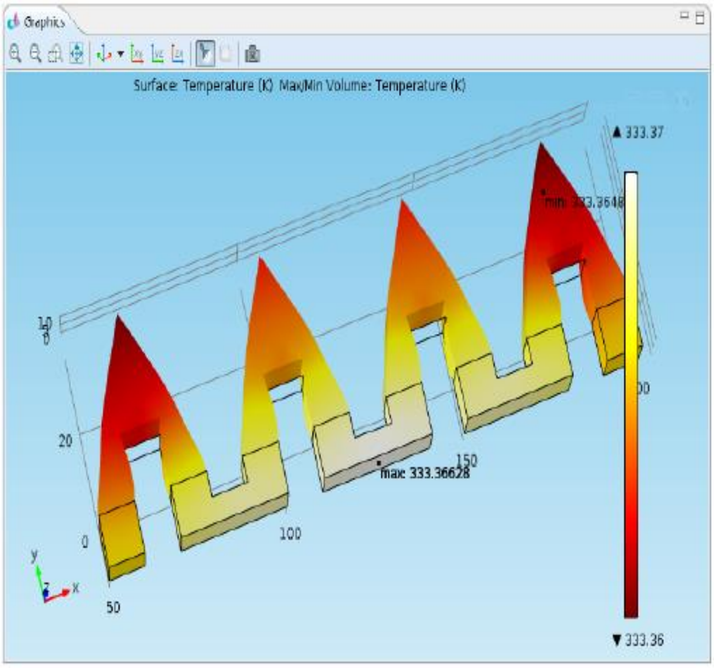

Fig. 3 Temperature Distribution of the Device

**Selection of Material**

The selection of material can be done by thermal analysis of different materials, by studying performance graph of temperature range of different materials as metals, semiconductor, insulator, polymers, alloys etc as shown in the Figures 4,5,6,7[1] below.

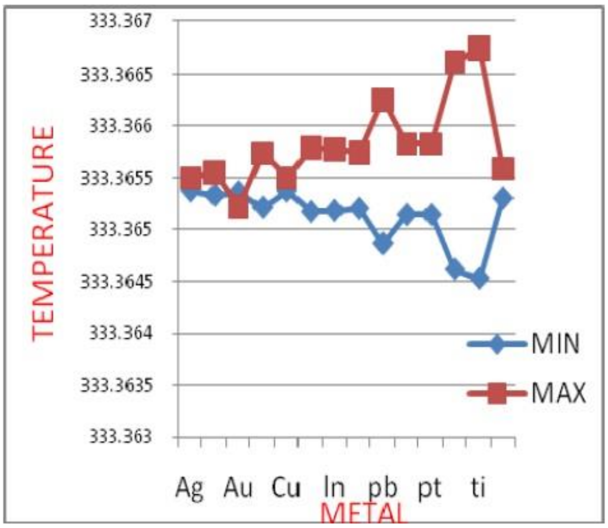

Fig.4 Metal Performance Graph

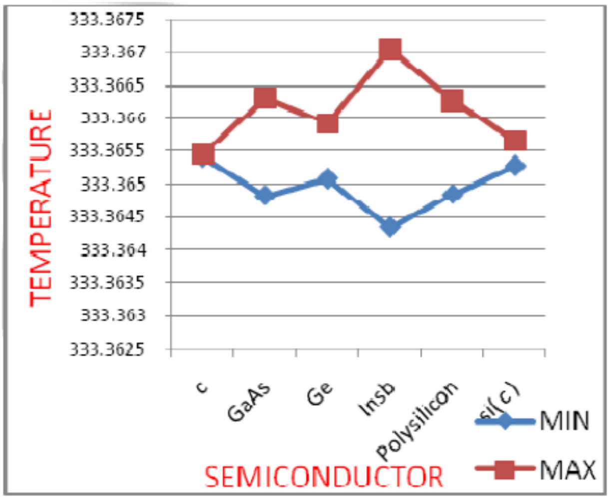

Fig.6 Semiconductor Performance Graph

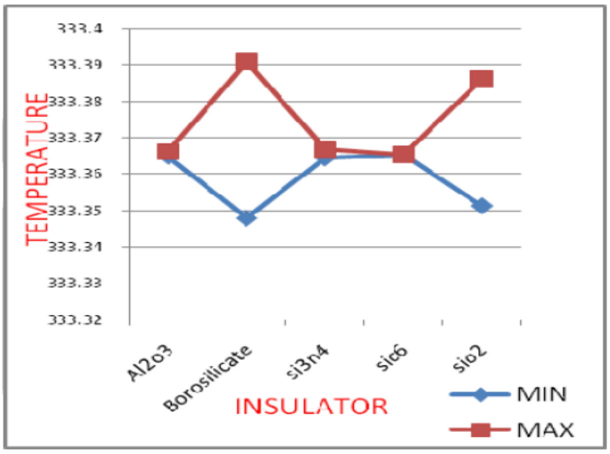

Fig.5 Insulator Performance Graph

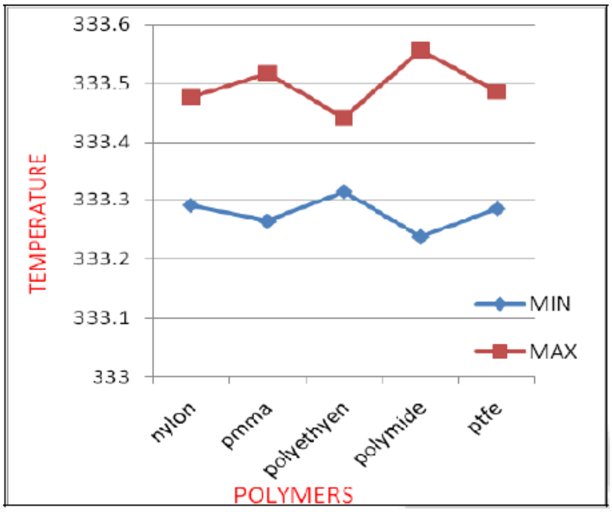

Fig.7 Polymers Performance Graph

Further study of displacement produced in an alloy by changing its temperature can also be used in the selection of material. [3]Figure 8 shows study of displacement produced by Copper Beryllium Alloy at different temperatures.

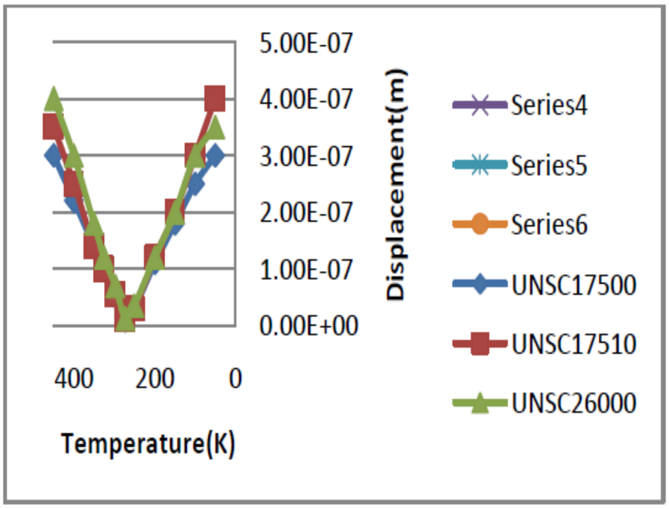

Fig.8 Temprature vs Displacement Graph

Thermal expansion can also be studied by studying displacement along the positions of the edge are also different at different temperatures for different alloys with electric potential applied.

The figure 9 shows the displacement of a curve that follows the top inner edges of the device from left to right. The outer arms of the device expand more & inner arms expand less. The maximum value of displacement increases from $7 *10^{-8}$ to $3.5 * 10^{-7}$ when we apply electric potential to the device [2].

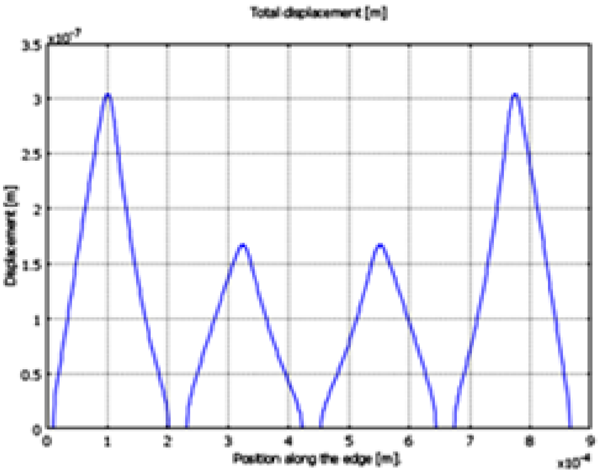

Fig. 9 Displacement vs Position Graph

The thermal expansion was occurred due to the heat transfer, so after the thermal stress applied, the polysilicon temperature sensor expands with some distance from the original position as shown in figure 10. This distance is measured in µmrange; it is called as a displacement of the device[1].

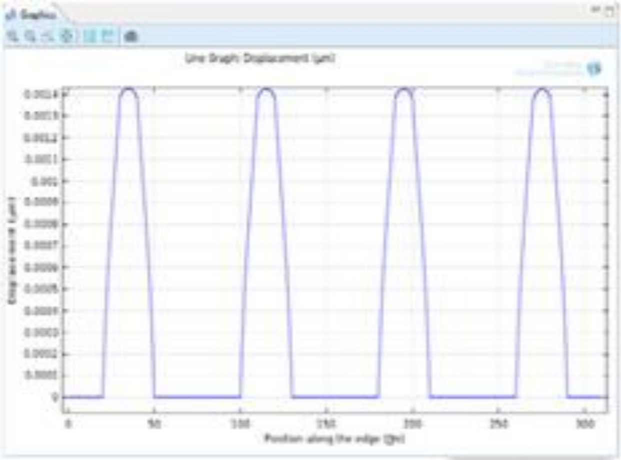

Fig. 10 Displacement along the edge

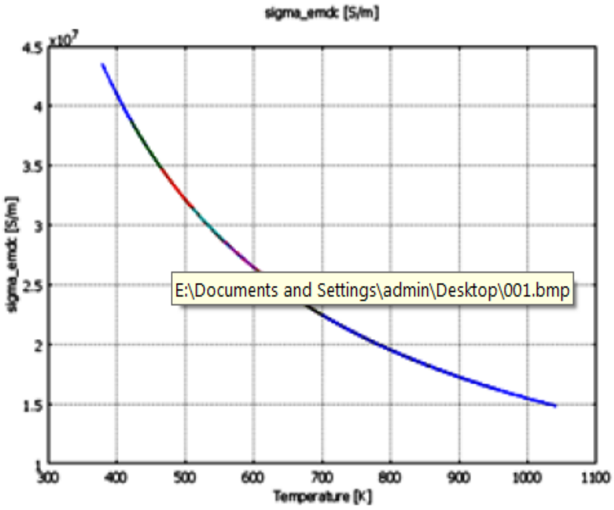

Fig. 11 Electrical conductivity of UNSC17500

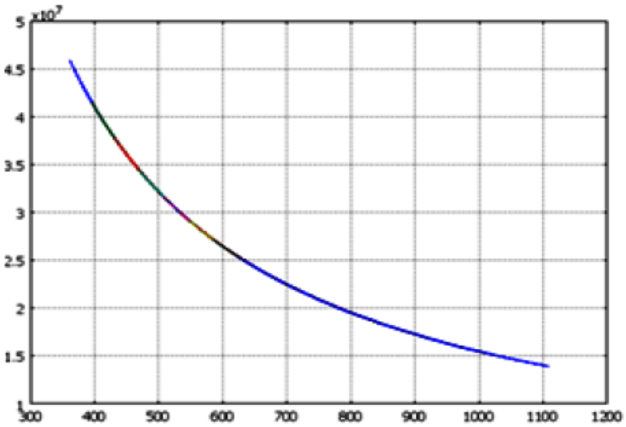

Fig. 12 Electrical Conductivity of UNSC26000

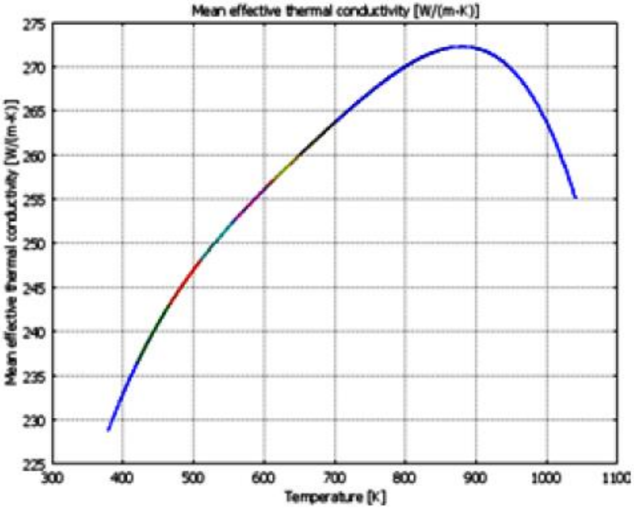

Fig. 13 Thermal Conductivity of UNSC17500

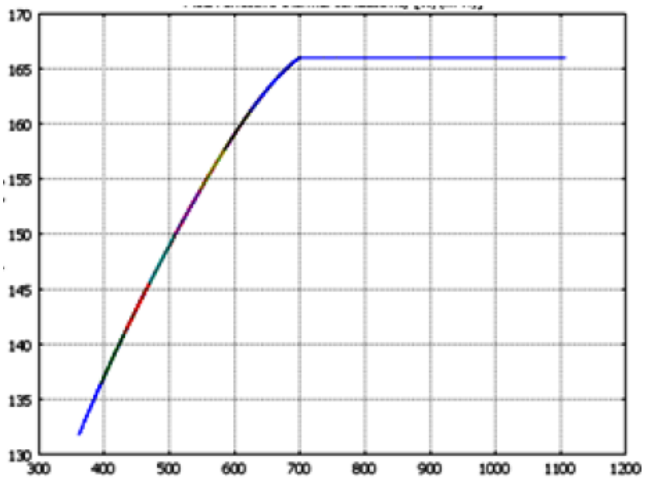

Fig. 14 Thermal Conductivity of UNSC26000

The electrical and thermal conductivity for different alloys for example beryllium copper alloy as UNSC17500, UNSC26000 is also different at different temperatures as shown in the figures above. Thermal Expansion is the type of actuator ie when we change temperature the material expands.

### To Interface COMSOL with MATLAB

LiveLink for MATLAB includes the COMSOL API Java, with all necessary functions and methods to implement models from scratch. For each operation you do in the *COMSOL Desktop* there is a corresponding command you can type at the MATLAB prompt. This is a simplified Java based syntax, which does not required any knowledge of Java. Available methods are listed in the *COMSOL Java API Reference Guide*. The simplest way to learn this programing syntax is to save the model as a M-file directly from the COMSOL Desktop.

## Conclusion

It can be concluded from the results, an array of sensors can be designed after analyzing the properties of different materials. Firstly the material is selected, by studying the temperature ranges of all the materials viz. metals, semiconductors, insulators, polymers and alloys. Secondly the displacement produced by different materials can be studied using the thermal expansion properties of materials. Many properties used to study thermal expansion may involve study of Joule Heating properties including mathematical equations, electrical and thermal conductivity after applying electrical potential to design this sensor array. So the sensor array can be designed using various shapes eg. U-shaped or zigzag etc.

## Acknowledgement

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## Future Work

Future work will involve study on various aspects of different materials and to interface COMSOL with MATLAB. And also evolving output using MATLAB.

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